Delineating Ecosystem Overfishing via Analysis of Ecosystem Indicator Inflection Points: Possible Ecosystem Reference Points

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Background

Global marine capture fisheries face notable challenges, which is only slightly less true of fisheries in the U.S. where many challenges remain (DOC 2008). We in NMFS often tend to not fully acknowledge the depth of these global challenges or our leadership role in providing means to solve them. The challenges facing global marine fisheries have been expressed in several ways, chief of which is the collapse of targeted stocks (sensu Botsford et al. 1997, NRC 1999, Jackson et al. 2001, Pitcher 2001, Pauly et al. 2002, 2003, Garcia and de Leiva Moreno 2003, Rosenberg 2003, Beddington and Kirkwood 2005, FAO 2007, Mullon et al. 2005, Berkes et al. 2006, Beddington et al. 2007). Both the global catch and the vast majority of the world's fish standing stock biomasses are either plateaued or trending down. Specifically, over ~70% of the world's fish stocks are at overfished or fully utilized levels (FAO 2007, NRC1999). Certainly many US stocks are now recovering and many are in a positive status, but the fact is that there are still many stocks in the US that are overfished or are experiencing overfishing (DOC 2008). We can debate the details regarding the exact level of remaining "virgin" biomass of many of these species (e.g., Myers and Worm 2003, Sibert et al. 2006, Hilborn 2006), but what is inescapable is that a significant fraction of these fish stocks have been removed and the sustainability of these harvests is in question. It is unclear whether these all of these stocks can recover and if the associated ecosystem impacts from their overfishing can be overcome (sensu Hutchings 2000, Pauly et al. 2002, Hutchings and Reynolds 2004, Worm et al. 2009). Even for those instances where particular fisheries stocks in any given ecosystem are not yet over-exploited, there is general recognition that, aside from a few rare instances, there is a significant risk of sequential depletion (sensu Link 2007) and ongoing ancillary impacts from fishing in an ecosystem remain (sensu Hall 1999, Jennings et al. 2001). That is, there are other impacts of fishing that can notably impact marine ecosystems. In this broad context, it would be helpful to have a leading indicator (or indicators) of such cumulative, negative circumstances, an indicator that would more rapidly and responsively convey the status of exploited marine ecosystems.

Several authors (e.g., Larkin 1996, Link 2002a, b, Garcia et al. 2003, Pikitch et al. 2004, Link 2010) have noted the need to adopt an ecosystem approach to fisheries management (EAF, aka ecosystem-based fisheries management, EBFM). By adopting an EBFM, there is built-in precaution and a recognition that by directly taking into account a broader range of factors, the mitigation and prevention of overfishing (and associated impacts) can be improved. There have been some promising attempts to implement EBFM (Pitcher et al. 2009), yet no one would yet say that EBFM has been fully implemented.

A key way to more operationally implement EBFM is to define, describe, explore and delineate ecosystem overfishing (EO). There have been a few first attempts to define EO (e.g., Murawski 2000, Jennings 2005, Link 2005, Samhouri et al. 2010). Recently there have been novel approaches that show some further promise to that end (Tudela et al. 2005, Libralto et al. 2008, Coll et al. 2008). Yet none of these have definitively nailed down delineations of EO that are broadly applicable for all situations in all ecosystems around the country or certainly the globe. The challenges of delineating EO are that it needs to be appropriate for both data poor and data rich situations, it needs to account for the multiple processes that influence living marine resources (LMRs) in marine ecosystems, and it needs to be based on reasonable ecological and resource exploitation theory.

As NOAA moves towards implementation of IEAs, there will be an increasing need to have integrative, synthetic, systematic indicators to explore system status. In fact, many of the elements of an IEA hinge upon having an adequate indicator set and have known inflection points among driver and response indicators (Levin et al. 2009, Samhouri et al. 2010).

We view the theoretical basis for developing EO definitions as follows. There is only a certain amount of productivity in any given ecosystem, conditioned upon environmental factors. How that production is ultimately allocated into various forms of biomass can be quite variable, and yet we have seen stability in total biomass for aggregate groups that are functionally redundant (Auster and Link 2009), often with a toggling of species prominence within groups after excessive exploitation (Link 2007). We also know that emergent, systemic properties tend to be more stable than individual stock and population dynamics. These systemic metrics also have inherent precaution as they purposefully account for species, technical, and energetic interactions and as such have tended to produce more conservative modeled thresholds than summing single species reference points (May et al. 1979, Brown et al. 1976). More so, by having such indicators used as possible EOs in place, many of the problems noted above for single species fisheries issues could be identified much earlier than they have been, and certainly seem to be better mitigated in simulation studies (Fulton et al. 2005, Fulton et al. in press).

By attempting to identify inflection points and thresholds on these more aggregate ecosystem properties, this project will provide both outputs and an approach to establish the basis for managing fisheries from a more systemic basis. Having these thresholds based upon the systemic level will detect regions of undesirability more quickly, mitigate and prevent ecosystem effects of fishing, and (on a positive note) as they are based on generally more stable factors, will allow for further market fungibility of harvested species, longer-term projections of economic planning, and more stable fishery yields--a cumulative result of more sustainable and economically viable fisheries.

Approach

What we propose to do in this project is to take a two-pronged approach to define, describe, explore and ultimately delineate ecosystem overfishing (EO). There have been analogous developments for single species fisheries reference points (e.g., Restrepo et al. 1998, Restrepo 1999) and toxicity thresholds (e.g., Suter 1993) for some time. This project will specifically seek to develop common patterns and utilize theory behind EO definitions that should ultimately be used in EBFM. The expectation is that by developing system-based reference points or associated control rules, one will be able assess and detect the negative cumulative impacts associated with over-exploitation more promptly than by waiting to see those effects in individual stocks. Conversely and positively, by developing thresholds for EO, one can remain in a more economically viable and sustainably harvesting situation (Edwards et al. 2004).

First, we will execute empirical analyses on one large marine ecosystem with many multiple metrics to explore and define EO. This will be for the ecosystem we primarily work in, the Northeast U.S. LME. Working in that ecosystem is very much a data rich situation and we will take advantage of the copious data sets here to identify those metrics, indicators and factors that explain most of the variance with respect to ecosystem dynamics. Candidate indicators, including both established indicators and others under development, are given in Table 1. We have a solid track record of doing so in prior studies (Link and Brodziak 2002, Link 2005, Methratta and Link 2006, EcoAP 2009). We will employ three analytical efforts here. First, we will explore a suite of univariate responses as a function of multiple "predictors" using GLMs, GAMs, or similar such statistical approaches. We have developed several of these analytical tools already (e.g., Liu et al., pers. comm., Link et al. 2010a). The second set of analytical tools will employ a suite of multivariate methods to ascertain those most important ecosystem responses to those main ecosystem drivers (fishing, environment, etc.). Again, we have done this in prior studies (e.g., Link et al. 2002, Link et al. 2010b) and thus have the tools extant to do so; however, we need to explore the broader range of updated indicators available (see listings in EcoAP 2009). Finally, once those canonical relationships are identified and univariate inflection points are suggested, we will employ a series of probit-logistical regression techniques to determine mathematical inflection points in the response metric/s relative to fishing (after controlling for environmental conditions in the 3rd dimension).

The second major effort will then extend this analysis from the NEUS to a national and then global perspective. We will execute an empirical analysis on many marine ecosystems and fewer metrics to further refine definitions and descriptions of EO. We and our workgroup at the NEFSC have been collaborators on a multiple US, EU, NCEAS, Australian, Sea Around Us, ICES working groups, and similar projects (e.g., Coll et al. 2010, Link et al. 2010b, Shin et al. 2010, Worm et al. 2009). From those collaborations and associated working groups, we will be able to access data to use a narrower list of response metrics (e.g., mean fish size, total fish biomass, etc.; c.f. Table 1) that are more readily available in data poor situations for a wider range of ecosystems. Again, we will employ the same three analytical methods to determine more broadly (i.e., with global and national representation) if there are common inflection points of various ecosystem indicators in response to fishing (as controlled for a much wider range of environmental conditions). These empirical approaches complement many of our modeling efforts (e.g., ICES 2009, Link et al. in press), which via simulation are beginning to explore the efficacy of these EO delineations.

Table 1. Candidate indicators to be used to explore and develop delineations of ecosystem overfishing (EO).

<table>
<tr><td colspan="2"></td><td>Possible Response Indicators</td></tr>
<tr><td colspan="2">Possible Driver or Pressure Indicators</td><td rowspan="4">Biomass-Abundance-Distribution of upper TL, functional groups, Zooplankton Biomass- Distribution, Benthic Biomass-Distribution, Community composition of benthos-zooplankton-fish communities, Throughput, Ascendency, Mass Flux per group, Size Spectra Slope parameters, Mean Size, Mean Trophic Level of groups, Mean trophic level of catches, Connectivity, Biodiversity indices, Keystone indices, Abundance indices of “canary” species, Abundance indices of selected Protected Spp., Percent Benthic habitat trawled, etc.</td></tr>
<tr><td>Climate & BioPhyscial Environmental Forcing</td><td>NAO, AMO, Gulf Stream Position, SST, Frontal Boundaries, Stratification Indices, Surface Salinity, Bottom Temperature, Proportional Thermal Habitat, etc.
(with many presented annually, by month, etc.)</td></tr>
<tr><td>Human Forcing</td><td>Human Development Index, Total Landings (and by functional groups), Total Human Population in coastal zone, # Vessel Permits, Total effort (and by fleets), etc.</td></tr>
<tr><td>Internal Forcing</td><td>Chlorophyll a, Primary Production, Mass Flux Indices, Phenology of blooms and thermal cycles, Total fish consumption, Number of trophic links, etc.</td></tr>
</table>

Benefits

There are few operational approaches in place for implementing IEAs. The benefit of successfully completing the proposed work would be to develop a set of highly portable analytical tools that we would make freely available to the scientific community, as well as identify the most appropriate indicators and levels of response for establishing EOs. Specifically, we would anticipate three major results.

First, we doubt that there will be just one metric or one set of metrics, just as there is not only one in single species stock assessments or toxicity lethalities. Based upon copious past experience, our sense is that there will be some commonly resulting metrics that center around systemic level biomass, production and size, but not any one metric in particular. The value of this approach is to note which metrics are most globally appropriate without going into the specifics of what each one needs to be, just as the analogous single species approach has generally noted the need to track some form of biomass or rate of replenishment (i.e. recruitment) contrasted with fishing or yield. Once these are determined some best practices and suggestions for common, national and global usage will be provided.

The second result which we expect is to develop a method or suite of methods that can help to establish ecosystem level definitions of overfishing, ultimately resulting in control rules that are partial functions of exploitation (i.e., fishing) but conditioned upon environmental factors. The latter point about being conditioned upon environmental drivers is a key distinction and requirement of this approach. Accounting for this will allow for generality in marine ecosystems as diverse as upwelling regions (US West Coast) to continental shelves (NEUS). Much like the inflection points of single species curves or toxicity studies have been used to develop control rules that define overfishing criteria, the hope here is to establish an approach to detect inflection points for the development of ecosystem overfishing criteria and associated control rules. Cognizant that some initial work has been conducted towards this end (e.g., Link 2005, Samhouri et al. 2010), we note that a common approach that flags common types of inflection or regions of inflection will build upon the theoretical basis from which these decisions need to be made. One could also readily envision these analytical elements as part of a national toolbox.

The final result of this work will be to demonstrate the concept in a pragmatic, practical, feasible manner that can be used in a wide range of marine ecosystems where exploitation (and perhaps even other ecosystem perturbations) and management of LMRs is an issue. As in prior works we have done, demonstrating the "proof of concept" has removed the technical barriers and perceptions of infeasibility so that EBFM can become even more fully implemented. Challenging and correcting misperceptions (as to the infeasibility of doing EBFM) is a fairly significant part of the process for EO (and more broadly, EBFM) to be implemented. Our sense is that by establishing definitions of ecosystem overfishing, eventually they will be enacted upon in a policy context. Changing the perception of feasibility by demonstrating that it can be done should not be underestimated as an important part of the process, removing any biases that both fisheries managers and scientists might have about how doable EBFM might be. Moving towards a policy of EBFM has been formally stated in many places in the world now and particularly as part of US marine policy; providing a tool (i.e., definitions of EO) to get there will escalate the rate at which those policies are enacted. Once EO are enacted (and there are currently several places around the world, including US fishery management councils, now looking for this type of input for their management process), the value-added benefit is that they will mitigate and prevent ecosystem overfishing, single species overfishing, and impacts from fishing more quickly as these aggregate, systemic metrics are more conservative and quicker to detect than are a series of sequential stock depletions.

Deliverables

- Regionally specific suggestions for delineating EO, conditioned upon environmental factors
- Global context, comparison, and validation of regional definition of EO
- Process, protocols and approaches that are globally (and certainly nationally) applicable for determining EO in an IEA context
- Supporting information for NEUS IEA efforts
- Suggestions for key indicators, processes to determine reference levels, and best practices of what those levels might be for national and global application of EO

Results from prior funding

Link, Fogarty, Mountain, Jacobson, Overholtz- Evaluating temperature induced shifts in stock location (Nye FY07-FY09 Postdoc): Shifts in distribution of 24 of 36 fish stocks as well as community assemblages were detected using 40 years of trawl survey data (Lucey and Nye 2010, Nye et al. 2009). A protocol was developed to determine what actions need to be taken to ensure that changes in distribution are adequately accounted for in stock assessment (Link et al. in review). Several ecosystem indicators were developed including an index of community preferred temperature which was included in the Ecosystem Status Report (EAP 2009).

References

Auster, P.J. & Link, J.S. (2009). Compensation and recovery of feeding guilds in a northwest Atlantic shelf fish community. Marine Ecology Progress Series 382: 163–172.

Beddington, J. R., G. P. Kirkwood (2005). The estimation of potential yield and stock status using life-history parameters. Philosophical Transactions of the Royal Society B, 360:163-170.

Beddington, J. R., D. J. Agnew, C. W. Clark (2007). Current problems in the management of marine fisheries. Science, 316:1713-1716.

Berkes, F., T. P. Hughes, R. S. Steneck, et al. (2006). Globalization, roving bandits, and marine resources. Science, 311:1557-1558.

Botsford, L. W., J. C. Castilla, C. H. Peterson (1997). The management of fisheries and marine ecosystems. Science, 277:509-515.

Brown, B., J. Breenan, M. Grosslein, E. Heyerdahl, R. Hennemuth (1976). The effect of fishing on the marine finfish biomass in the Northwest Atlantic from the Gulf of Maine to Cape Hatteras. ICNAF Research Bulletin, 12:49-68.

Coll, M., S. Libralato, S. Tudela, I. Palomera, F. Pranovi (2008) Ecosystem overfishing in the ocean. Public Library of Science (PLOS) ONE 3(12): e3881. doi:10.1371/journal.pone.0003881.

Coll, M., Shannon, L.J., Yemane, D., Link, J., Ojaveer, H., & Shin, Y-J. (2010). Ranking ecological relative status of exploited ecosystems using multiple indicators. ICES Journal of Marine Science 67: 769-786.

DOC (Department of Commerce) (2008). Fisheries of the United States, 2007. Silver Spring, MD: United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Science and Technology.

Ecosystem Assessment Program (EcoAP). (2009). Ecosystem Status Report For the Northeast U.S. Continental Shelf Large Marine Ecosystem. Northeast Fisheries Science Center Reference Document, 09-11. 34 p.

Edwards, S. F., J. S. Link, B. P. Rountree (2004). Portfolio management of wild fish stocks. Ecological Economics, 49:317-329.

FAO (Food and Agriculture Organization) (2007). The State of the World Fisheries and Aquaculture 2006. Rome, Italy: FAO, pp 162.

Fulton, E. A., A. D. M. Smith, A. E. Punt (2005). Which ecological indicators can robustly detect effects of fishing? ICES Journal of Marine Science, 62:540-551.

Fulton, E.A., J.S. Link, I. Kaplan., M. Savina-Rolland, P. Johnson., C. Ainsworth, P. Horne, R. Gorton, R.J. Gamble, A.D.M. Smith, D.C. Smith. (In Press). Lessons in modelling and management of marine ecosystems: The Atlantis experience. Fish and Fisheries

Garcia, S. M., I. d. L. Moreno (2003). Global overview of marine fisheries. In: Sinclair, M., G. Valdimarsson (eds), Responsible Fisheries in the Marine Ecosystem. Wallingford, UK: CAB International.

Garcia, S. M., A. Zerbi, C. Aliaume, T. Do Chi, G. Lasserre (2003). The Ecosystem Approach to Fisheries: Issues, Terminology, Principles, Institutional Foundations, Implementation and Outlook. FAO Fisheries Technical Paper 443. Rome, Italy: FAO, pp 71.

Hall, S. J. (1999). The Effects of Fishing on Marine Ecosystems and Communities. Malden, MA: Blackwell Science Ltd.

Hilborn, R. (2006). Faith-based fisheries. Fisheries, 31:554-555.

Hutchings, J. A. (2000). Collapse and recovery of marine fishes. Nature, 406:882-885.

Hutchings, J. A., J. D. Reynolds (2004). Marine fish population collapses: consequences for recovery and extinction risk. BioScience, 54:297-309.

ICES. 2009. Report of the Working Group on Multispecies Assessment Methods (WGSAM), 5–9 October 2009, ICES Headquarters, Copenhagen. ICES CM 2009/RMC:10. 117 pp.

Jackson, J. B. C., et al. (2001). Historical overfishing and the recent collapse of coastal ecosystems. Science, 293:629-638.

Jennings, S. (2005). Indicators to support an ecosystem approach to fisheries. Fish and Fisheries, 6:212-232.

Jennings, S., M.J. Kaiser, J.D. Reynolds. (2001). Marine Fisheries Ecology. Blackwell Science, Oxford, UK. 417 pp.

Larkin, P. A. (1996). Concepts and issues in marine ecosystem management. Reviews in Fish Biology and Fisheries, 6:139-164.

Levin P. S., M. J. Fogarty, S. A. Murawski, D. Fluharty (2009) Integrated ecosystem assessments: developing the scientific basis for ecosystem-based management of the ocean. Public Library of Science (PLOS) Biology 7(1): e1000014 (0023-0028).

Libralato, S., M. Coll, S. Tudela, I. Palomera, F. Pranovi (2008). Novel index for quantification of ecosystem effects of fishing as removal of secondary production. Marine Ecology Progress Series, 355:107-129.

Link, J. S. (2002a). Does food web theory work for marine ecosystems? Marine Ecology Progress Series, 230:1-9.

Link, J. S. (2002b). Ecological considerations in fisheries management: when does it matter? Fisheries, 27:10-17.

Link, J. S. (2005). Translation of ecosystem indicators into decision criteria. ICES Journal of Marine Science, 62:569-576.

Link, J. S. (2007). Under-appreciated species in ecology: “ugly fish” in the Northwest Atlantic Ocean. Ecological Applications, 17:2037-2060.
Link, J.S. (2010). Ecosystem-based fisheries management: confronting tradeoffs. Cambridge Univ. Press. Cambridge, UK. 224 pp.
Link, J. & Brodziak, J. (eds.). (2002). Report on the Status of the NE US Continental Shelf Ecosystem. NEFSC Ecosystem Status Working Group. Northeast Fisheries Science Center Reference Document 02-11, 245 pp.
Link, J.S., Brodziak, J.K.T., Edwards, S.F., Overholtz, W.J., Mountain, D., Jossi, J.W., Smith, T.D. & Fogarty, M.J. (2002). Marine Ecosystem Assessment in a Fisheries Management Context. Canadian Journal of Fisheries and Aquatic Sciences 59:1429-1440.
Link, J.S., B.A. Megrey, T.J. Miller, T. Essington, J. Boldt, A. Bundy, E. Moksness, K.F. Drinkwater & R. I. Perry. (2010a). Comparative Analysis of Marine Ecosystems: International Production Modelling Workshop. Biol. Lett. doi: 10.1098/rsbl.2010.0526
Link, J.S., Yemane, D., Shannon, L.J., Coll, M., Shin, Y-J., Hill, L., Borges, M.F., Bundy, A. & Aydin, K. (2010b). Relating Marine Ecosystem Indicators to Fishing and Environmental Drivers: An Elucidation of Contrasting Responses. ICES Journal of Marine Science 67: 787-795.
Link, J.S., E.A. Fulton, and R.J. Gamble (In Press). The Northeast US Application of ATLANTIS: A full system model exploring marine ecosystem dynamics in a living marine resource management context. Progress in Oceanography.
May, R. M., J. R. Beddington, C. W. Clark, S. J. Holt, R. M. Laws (1979). Management of multispecies fisheries. Science, 205:267-277.
Methratta, E.T. & Link, J.S. (2006). Evaluation of Quantitative Indicators for Marine Fish Communities. Ecological Indicators 6:575-588.
Mullon, C., P. Fréon, P. Cury (2005). The dynamics of collapse in world fisheries. Fish and Fisheries, 6:111-120.
Murawski, S. A. (2000). Definitions of overfishing from an ecosystem perspective. ICES Journal of Marine Science, 57:649-658.
Myers, R. A., B. Worm (2003). Rapid worldwide depletion of predatory fish communities. Nature, 423:280-283.
NRC (National Research Council) (1999). Sustaining marine fisheries. Washington, D.C.: National Academy Press.
Pauly, D., V. Christensen, S. Guénette, et al. (2002). Towards Sustainability in World Fisheries. Nature, 418:689-695.
Pauly, D., J. Alder, E. Bennett, et al. (2003). The Future for Fisheries. Science, 302:1359-1361.
Pikitch, E. K., C. Santora, E. A. Babcock, et al. (2004). Ecosystem-based fishery management. Science, 305:346-347.
Pitcher, T. J. (2001). Fisheries managed to rebuild ecosystems? Reconstructing the past to salvage the future. Ecological Applications, 11:601-617.

Pitcher, T. J., D. Kalikoski, K. Short, D. Varkey, G. Pramod (2009). An evaluation of progress in implementing ecosystem-based management of fisheries in 33 countries. Marine Policy, 33:223-232.

Restrepo, V. R. (1999). Proceedings of the Fifth National NMFS Stock Assessment Workshop: Providing Scientific Advice to Implement the Precautionary Approach Under the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Technical Memorandum NMFS-F/SPO 40. pp 161.

Restrepo, V. R., G. G. Thompson, P. M. Mace, et al. (1998). Technical Guidance on the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Technical Memorandum NMFS-F/SPO 31. pp 54.

Rosenberg, A. A. (2003). Managing to the margins: the overexploitation of fisheries. Frontiers in Ecology and the Environment, 1:102-106.

Samhouri JF, Levin PS, Ainsworth CH (2010) Identifying Thresholds for Ecosystem-Based Management. PLoS ONE 5(1): e8907. doi:10.1371/journal.pone.0008907

Shin, Y.-J., L.J. Shannon, A. Bundy, M. Coll, J.L. Blanchard, M.-F. Borges, J. Cotter, P.M. Cury, J.J. Heymans, D. Jouffre, J.S. Link, C. Möllmann, H. Ojaveer, K.O.M. Abdallahi, M.-J. Rochet, & D. Yemane. (2010). Using indicators for evaluating, comparing and communicating the ecological status of exploited marine ecosystems. Part 2: Setting the scene. ICES Journal of Marine Science 67: 692-716.

Sibert, J., J. Hampton, P. Kleiber, M. Maunder (2006). Biomass, size, and trophic status of top predators in the Pacific Ocean. Science, 314:1773-1776.

Suter, G. W. (1993). Ecological Risk Assessment. Boca Raton, FL: Lewis Publishers, Inc.

Tudela, S., M. Coll, I. Palomera (2005). Developing an operational reference framework for fisheries management on the basis of a two-dimensional index of ecosystem impact. ICES Journal of Marine Science, 62:585-591.

Worm, B., R. Hilborn, J. Baum et al. (2009). Rebuilding global fisheries. Science. 325:578-585.